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THE MINERAL INDUSTRY IN VIRGINIA IN 1976[1]

ADVANCE SUMMARY

Virginia's total mineral production in 1976 was valued at $1,160,600,000, a decrease of 8 percent below that of 1975. The decline in mineral production value, the first in many years, was primarily due to a decrease in the value of bituminous coal (Table 1). However, bituminous coal continued to be the Commonwealth's leading mineral commodity; total tonnage was 39,996,000 short tons, valued at $964,669,000, an increase of 12 percent in output, but a decrease in value of 11 percent below that of 1975. It comprised 83 percent of the total mineral production value of the Commonwealth compared to 86 percent in 1975.

Production of stone, the second leading mineral commodity, increased 9 percent in tonnage and 2 percent in value over that of 1975. Other leading mineral commodities, in descending order of value, were cement (masonry and portland), lime, and sand and gravel.

Several commodities whose values are concealed increased in both output and value. Kyanite production increased 11 percent and value increased 19 percent. Gypsum production and value more than trebled while the value of talc doubled with only a slight increase in output.

Natural gas production increased 3 percent, but value more than doubled. Crude petroleum production remained about the same.

Zinc production declined 26 percent and value 30 percent; lead production decreased 24 percent and value 18 percent. Silver, recovered from the smelting of lead and zinc, declined in production and value.

[1]Prepared in the U.S. Bureau of Mines Liaison Office—North Carolina and Virginia, Raleigh, NC, under a cooperative agreement between the Bureau and the Virginia Division of Mineral Resources.

THE MINERAL INDUSTRY IN VIRGINIA IN 1977[2]

PRELIMINARY DATA (SUBJECT TO CHANGE)

Preliminary information shows that the total value of mineral production in Virginia in 1977 was $1,128,000,000 according to estimates by the U.S. Bureau of Mines (Table 1). This was a decrease of 3 percent below that of 1976. Of the total mineral value approximately 82 percent was contributed by fuels, 17 percent by nonmetals, and 1 percent by metals.

[2]Prepared in the U.S. Bureau of Mines Liaison Office—North Carolina and Virginia, Raleigh, NC, under a cooperative agreement between the Bureau and the Virginia Division of Mineral Resources.

The estimated production of bituminous coal decreased 7 percent to approximately 36,990,000 tons and output value decreased from $964,669,000 in 1976 to an estimated $910,000,000 or 5 percent in 1977. Natural gas production increased significantly, but crude petroleum production remained about the same.

Stone increased 6 percent in tonnage and 11 percent in value; sand and gravel decreased 5 percent in output and 4 percent in value; lime production was down slightly in tonnage, but value increased 13 percent; and cement tonnage and values increased moderately.

Zinc production increased 18 percent and value 10 percent over that of 1976; lead tonnage increased 13 percent and value 50 percent. Silver recovery more than doubled.

Table X.—Mineral production in Virginia.[1]

Mineral	1975 Quantity	1975 Value (thousands)	[2]1976 Quantity	[2]1976 Value (thousands)	[3]1977 Quantity	[3]1977 Value (thousands)
Clays .... thousand short tons	819	$ 1,152	862	$ 1,210	865	$ 1,443
Coal .... do	35,510	[4]1,081,587	39,996	964,669	36,990	910,000
Gem stones	NA	13	NA	12	NA	10
Lead (recoverable content of ores, etc.) .... short tons	2,551	1,097	1,946	899	2,200	1,346
Lime .... thousand short tons	705	20,192	878	25,993	839	29,480
Natural gas .... million cubic feet	6,723	3,462	6,937	7,908	8,750	10,325
Petroleum (crude) .... thousand 42-gallon barrels	3	W	3	W	2	28
Sand and gravel .... thousand short tons	9,895	24,776	[5]10,191	[5]23,089	[5]9,700	[5]22,300
Stone .... do	35,384	84,204	36,132	91,723	38,189	102,139
Zinc (recoverable content of ores, etc.) .... short tons	15,151	11,818	11,241	8,319	13,300	9,150
Value of items that cannot be disclosed: Aplite, cement (masonry and portland), gypsum, *iron ore* (1976), kyanite, sand and gravel (industrial, 1976, 1977), silver, talc, and values indicated by symbol W	—	33,673	—	36,823	—	41,433
Total	—	[4]1,261,974	—	1,160,645	—	1,127,654

NA Not available. W Withheld to avoid disclosing individual company confidential data.

[1]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

[2]Revised from figures given in *Virginia Minerals*, vol. 23, no. 1, p. 7, February 1977.

[3]Preliminary data; subject to revision.

[4]Revised from figures given in *Virginia Minerals*, vol. 22, no. 1, p. 2, February 1976 and vol. 23, no. 1, p. 7, February 1977.

[5]Excludes industrial sand and gravel; value included with "Value of items that cannot be disclosed."

REPLENISHING NON-RENEWABLE MINERAL RESOURCES—A PARADOX[1]

Richard P. Sheldon[2]

In 1922 a joint committee of petroleum geologists from the American Association of Petroleum Geologists and the U.S. Geological Survey estimated that the United States had only 9 billion barrels of oil left in the ground either as reserves or as resources to be discovered (U.S. Geological Survey, 1922). Eleven years later, the 9 billion barrels had been produced and an additional 13 million barrels had been discovered.

In 1952 the President's Materials Policy Commission estimated the Nation's foreseeable copper re-

[1]Reprinted from a portion of "United States Geological Survey Yearbook, Fiscal Year 1977", p. 41-47.

[2]Geologist, U. S. Geological Survey.

source (as of 1950) to be 25 million tons. Twenty-five years later, 31 million tons of copper had been produced and an additional 57 million tons of reserve had been discovered.

These are two of many examples of carefully reasoned mineral resource predictions by credible highly qualified geologists and engineers that have been overtaken in a few tens of years by additional production and discovery.

Mineral resource estimates ordinarily are requested by national planners when they perceive possible future shortages. The 1922 oil estimate was made during the "John Bull" oil shortage scare, and the 1952 copper estimate was undertaken during the post-World War II period when the United States was thought to be "outgrowing its resource base." The engineers and geologists responsibly furnish these estimates, usually qualifying them as conservative, particularly in regard to minerals expected to be added by additional discovery. Unfortunately, such qualifiers are quite often dropped by many of those who use the estimates. These estimates generally deepen the concern over impending shortage, but become irrelevant when the period of shortage gives way to a period of adequate or even over supply.

Behavior of these non-renewable mineral resources over time is opposite to what we intuitively expect. Geologists and engineers measure and report resource abundance. The resources they estimate are then depleted at ever increasing rates that foreseeably should exhaust the resource. Concern about shortages grows. Yet when the time approaches when we should have run out of the resource, we find paradoxically—almost alchemically—that we have more than we started with. At best we distrust the forecaster's ability and at worst his motives. What has gone wrong? Are such underestimates going to continue to be made in the future? To answer these questions, the nature and dynamics of resources need to be understood.

NATURE OF RESOURCES

In Webster's dictionary, a resource is defined as a fresh or additional stock or store of something available at need. Thus, in the short term, we think of resources as a stockpile of inventoried material with immediate availability. If we consider long-term demand, the question of future availability becomes important, so that undeveloped resources, that is mineral resources awaiting discovery in the ground or living resources yet to be born or planted, must be considered. Thus resources have two essential characteristics: (1) a demand, and (2) an availability. Depending on the time frame being considered, the demand and the availability are either immediate or potential.

Resource demand. Potential resources are based on a projection of future demands, a process that carries some risk. For example, in view of the threatening deforestation in France in the late 17th century, the King planted an oak forest near Paris as a reserve to supply, some 200 years hence when the trees matured, oak logs for masts and timbers for warship construction. His foresight created a beautiful forest that still stands, but did little to meet the needs of the modern French Navy.

The changing nature of mineral resource demand and its affect on resources over time can be seen by considering the mineral resources of the State of Montana at two times: a thousand and ten years ago and ten years ago.

On the one hand, the stone-age Indian living in 968 in what was to become Montana had a very small but highly specialized need for stones. Each year he used a few pounds of flint and obsidian for tools, arrowheads, and axe heads, a few pounds of sandstone for mortars, a little salt and mineral dye. Their value at today's prices would be a few cents, or at his prices, a few belts of wampum. The total resources available in his shallow quarries would be worth perhaps a few thousands of dollars in our terms. Of course, he used so little of his mineral resource that their eventual depletion was of little if any concern to him.

On the other hand, the industrial-age Montanan living in 1968 had tremendous needs for minerals, and huge production facilities and mineral resources to meet them. Along with his fellow citizens from the other 49 states, the Montanan used, on the average, 20 tons of minerals a year. The value of the cumulative mineral production of Montana from 1880 up to 1960 was over 4 billion dollars, showing that Montana lives up to its name, the Treasure State. In 1968, Montana contained 52 varieties of significant mineral deposits ranging from asbestos to vermiculite (U.S. Geological Survey, 1968). The most important of these were oil, natural gas, coal, copper, phosphate rock, and chromium. Their reserves at that time were worth 1.17 trillion dollars.

The mineral needs of the stone-age Montanan were low, and his assessed resources were correspondingly low. On the other hand, the mineral needs of the industrial-age Montanan are large and varied, but so are his mineral resources. The difference in mineral needs, supplies and resources between the two ages is staggering. It is no matter that the stone-age Montanan was standing on vast deposits of minerals that were to become highly valuable to Montanans a millenium later. To him they were rocks to walk on, not resources to use. The separation of ages is complete when one realizes that the industrial-age Montanan does not even include among his vast mineral resources the small deposits of flint, obsidian and sandstone used by his predecessor a millenium earlier.

It is clear from considering this example that even though most mineral deposits are permanent and unchanging on the human time frame, mineral resources are temporal and changing. V. E. McKelvey pointed out (1972, p. 20) that, "Defining resources as materials usable by man, a little reflection reveals that whereas it is God who creates minerals and rocks, it is man who creates resources." One can reflect further that a mineral *deposit* can be characterized as non-newable, but mineral *resources* are another thing entirely. By additional effort by man new mineral resources can be "created," not in the sense of creation by the Almighty, but in the sense that a body of rock is identified for the first time as useable. Within the limits of geologic availability, one can conclude that the character, variety and size of mineral resources depend on the technology that needs them and the technology for developing them.

Resource availability. To be anything other than a wishful thought, resources must be available or potentially so. A mineral deposit that has been found, measured, and determined to be economically mineable at the current price using current mining and extraction technology is available and clearly a resource. If the deposit is known and measured, but no process is known or foreseen by which the material can or could be recovered economically, it is not available for use and is not a resource. However, if it seems to qualified engineers technologically feasible to develop in the future a process to recover the material economically, the deposit would be potentially available for use and would be called a sub-economic resource (U.S. Bureau of Mines, and the U.S. Geological Survey, 1976). For example, in 1950, when the 6.2 billion tons of U.S. iron ore reserve included no taconite, the low-grade taconite deposits were sub-economic and were foreseen to be only potentially available. The developing of the technology to drill, mine and concentrate taconite made it economic and, in fact, the preferred ore, which in 1975 made up most of the U.S. iron ore reserve of 17 billion tons.

Another factor of availability is the knowledge of the existence of a deposit. It is obvious that a deposit must be identified to be available and that an undiscovered deposit is unavailable. Exploration and resource geologists can identify areas where undiscovered deposits might occur and then can make a knowledgeable guess about how many deposits exist there, and of these how many might be discoverable. They also can make knowledgeable guesses about the size of such undiscovered deposits. Such deposits can then be considered potentially available; that is we have the potential to discover them with current exploration techniques. Nearly all of our known deposits that now make up our past production and present mineral reserve were once a part of the undiscovered but discoverable resource.

There is no way in which the ultimate amount of the undiscovered resources can be determined even though some portions of the ultimate amount can be estimated. We can predict a discoverable portion of undiscovered resources using well supported *hypotheses* of the occurrence of deposits, as well as an additional discoverable portion using poorly supported *speculations* on the occurrence of deposits. These portions make up the *hypothetical* and *speculative* categories of undiscovered resources used by the Geological Survey and the Bureau of Mines. However, a still further portion of undiscovered ultimate resources cannot be predicted because it is undiscoverable using either current or forseeable future exploration technology. For example, some rocks of the western United States are mineralized where they are exposed, but in large areas where they are covered by younger lava flows, they cannot be prospected for by anything other than the too-expensive drill or shaft. Geologists can confidently predict that many deposits exist beneath the lava flows but the deposits are not economically discoverable with present or foreseeable future technology and cannot be counted as a part of our resources. A still further portion of undiscovered ultimate resources cannot be predicted because of lack of scientific evidence of the existence of the deposits. Such deposits probably exist but are unsuspected by geologists. A clear hindsight example of such a deposit is the Red Sea metalliferous mud. On February 17, 1965, marine geologists on the oceanographic research vessel, *R. V. Atlantis, II,* were astonished to find that a core of mud taken in the central part of the Red Sea was enriched in zinc, copper, lead, silver, and gold (Degens and Ross, 1969). Subsequent surveys showed that the metalliferous muds in the Red Sea are widespread, fairly thick and contain large quantities of scarce metals. These deposits now are a part of the world's sub-economic resource, but there was no reason whatever before their chance discovery to suspect that they existed. They were totally unconceived and were certainly not visualized as a part of undiscovered resources.

RESOURCE FLOW

A common but incorrect way of viewing mineral resources is to regard them as the sum of the known and predicted economic deposits of commodities in current use, and from that to conclude that mineral resources in general are fixed and non-renewable. As seen in the discussion in the previous section, mineral resources consist of known and suspected mineral deposits that are counted as resources by virtue of industrial needs for them and subsequently are categorized according to knowledge of their existence, the economics and technology of their discovery, and the economics and technology of their mining and extraction. These factors change over time, causing the make-up and magnitude of resouces to change. Recognizing that resources are so heavily influenced by these temporal economic factors, economists David Brooks and P. W. Andrews pointed out in 1974 that in matters of long-term supply, minerals should be treated not as a fixed stock, but as a flow that responds to demand.

The misconception of resources as a fixed stock answers part of the question raised at the start of this paper, "What has gone wrong with our mineral forecasting?" At a time of concern over threatening shortages of minerals, resource geologists and engineers are asked to join forces and estimate the known mineral resources and predict the unknown mineral resources. They would like to estimate once and for all the total or ultimate resources of the country, but they cannot. Their problem is this—both geologists and engineers, no matter how technically liberal they may be, must stay within the confines both of their data and their technical understanding and methodology. They come up with estimates, but each one is outdated the day it is published, because continuing exploration and study generate new data, and new basic research sparks new ideas of occurrence or recovery. In the past, most estimates have turned out to be too low, which is expectable. Regardless of the liberalism of the estimater, the methodologic conservatism that must be followed insures that the estimate will exclude deposits that are unrecoverable with foreseeable technology as well as deposits that are undiscoverable—as were the mineral deposits beneath basalt flows—or are unpredictable—as were the Red Sea metalliferous muds. Over time with the accumulation of more knowledge, significant amounts of such deposits will become recoverable, discoverable or predictable and add to the total resources.

This is not to say that rocks, minerals, and their natural concentrations are not finite or that geologic availability is not a limiting factor in resource magnitude, but only that the conception and perception of resources at any given time are likely to be limited.

MINERAL SUPPLY SYSTEM

The mineral supply system of the United States yields this flow of most mineral materials from one resource category to another progressively from speculative-undiscovered resources to refined material production. As we have seen, the system is driven by the demands of the industrial-age.

To understand how this supply system works and the factors influencing it, one must look at its components. It is commonly conceived to have three major phases: research, exploration, and exploitation; however, each of these phases is divided into two parts. Research consists of conception and assessment of undiscovered resources; exploration consists of discovery and delineation of mineral deposits; and exploitation consists of extraction and processing of ores. Table 2 shows this breakdown along with the actual activity carried out, the mineral resource category developed, and the institutions with the prime responsibility.

The flow of material is initiated by research organizations in government, academic, and the private sector conducting basic research on geologic processes of rock and mineral formation and distribution. Originally all resources were unconceived, and only by such basic study and thinking was each kind of deposit conceived. Once conceived, the magnitude, location and character of the deposits are speculated on and reported as a *speculative* undiscovered resource, generally by government and academic research organizations.

In the next phase, mineral resources are further defined by government resource agencies and to a lesser degree (and mainly for its own purposes) by the exploration sector of industry. They conduct geologic,geophysical, and geochemical mapping of areas of speculative resources. Application of well-supported hypotheses concerning the occurrence of mineral deposits to these regional data allows estimation of *hypothetical undiscovered resources*. In this way the certainty of actual existence of the undiscovered resource is increased to the point that the hypothetical resource estimates have sufficient reliability for national planning in government or exploration planning in industry.

At this point exploration is initiated by industry. The regional maps produced at the assessment stage are used to plan a prospecting program. More detailed field studies are carried out to narrow the target areas, and finally drilling or tunneling is undertaken to search for the deposit. This activity, when

Table 2.—Phases of mineral supply system.

Major phases	Detailed phases	Activity		Mineral resource category developed	Prime responsibility
RESEARCH	CONCEPTION	Research in geologic processes, i.e. plate tectonics, formation of mineral deposits, etc.	UNDISCOVERED RESOURCES	SPECULATIVE	Universities, Government, research organizations, private institutes
	ASSESSMENT	Geologic, geophysical, and geochemical mapping, geostatistical analysis		HYPOTHETICAL	Government Industry
EXPLORATION	DISCOVERY	Prospecting	RESERVES	INFERRED	Industry
		Research on prospecting techniques			Government and Industry
	DELINEATION	Exploration		INDICATED AND MEASURED	Industry
		Research on exploration techniques			Industry and Government
EXPLOITATION	EXTRACTION	Mining and land reclamation		Produced raw material	Industry
		Research and development on extraction		Reserves	Industry and Government
	PROCESSING	Beneficiation reduction and refining		Produced refined material	Industry
		Research and development on processing		Reserves	Industry and Government

successful, develops *reserves* of the *inferred* class. Further detailed exploration improves the accuracy of the reserve estimate by better delineating the extent and shape of the deposit as well as its grade and mineralogy. This activity develops *indicated and measured reserves* which have the degree of certainty necessary for the investment by industry of large amounts of capital needed for exploitation of the deposit.

The mineral supply system consists of a series of sequential steps, each one necessary for the initiation of the succeeding step, and each one designed to improve the effectiveness and economic efficiency of the total system. The demand for minerals drives the resource flow. The overall economic efficiency of this system is set by the technologic level and is improved by research and development at all phases. That is to say, the estimated magnitude of undiscovered resources is increased by improved basic concepts of mineral deposits and mapping and resource assessment of potentially mineralized areas. Reserves are increased by prospecting, which is made more effective by improvement of prospecting, extraction and processing techniques. The increase in resources over time is directly related to the amount of effort put into improving the technology as well as to the amount of exploration effort. That is to say, we replenish, expand and diversify our "non-renewable" mineral resources by technologic advance through research and development effort.

LONG-TERM MINERAL SUPPLY

Our mineral resources are replenished by scientific and technologic advance, but how long can this keep up? Even with replenishment, will we eventually outgrow our mineral resource base? Much thought has been given to this question and much diversity of opinion exists. Economic geologist, B. J. Skinner, in an article titled, "A second iron age ahead?" (1976) predicts that the day when "we will have to come to grips with the way in which the earth offers us its riches . . . is less than a century away, perhaps less than a half century. When it dawns we will have to learn to use iron and other abundant metals for all our needs." On the other side, resource economist, J. F. McDivitt (1974) believes that ". . . if the peoples of the world continue to work closely together and to move towards an ever more efficient pattern of resource use . . .

mineral shortages will continue to be only a faint cloud on the world's horizon."

The mineral supply system certainly will have to deal in the long term with serious constraints if it is to keep up with demand. First of all, demand itself has been growing exponentially and, of course, that sort of growth cannot continue. Brooks and Andrews (1974) have suggested that "relative demands (for minerals) decline after a point with increase in per capita income. Indeed . . . the relative growth is sufficiently damped that it was suggested in one study that mineral production will need to grow less fast in the future than it has grown in the recent past, exactly the opposite of most conclusions based on trend analysis." This is the same sort of hopeful sign that in recent years we have witnessed in some population growth in reaction to increased per capita income. Another constraint to the long-term mineral supply system is a threatened shortage of energy. Much of the technologic advance that replenishes mineral resources is energy intensive, so this could be a serious future contraint and in fact, the rise in energy costs in the last years has been severely felt in most parts of the mining industry. Another present major constraint that could increase even more is the accommodation of the mineral supply system to the regulatory controls and costs concerned with environmental pollution and degradation as well as to the public desire to withdraw from mineral entry all public lands judged better used as a wilderness or an ecologic reserve. Another possible constraint is what B. J. Skinner calls the "mineralogical barrier." Scarce metals in the earth's crust, such as copper, lead, nickel, tin, and tungsten, are mostly disseminated within the atomic structure of host minerals that make up common rock. In that way they are accessible to recovery only by chemically breaking down the host minerals, a feat which requires very large amounts of energy. Such scarce metals are now recovered from the geologically rare deposits in which they occur as a principal component. Geologist Skinner believes that such deposits will soon be depleted. Economists Brooks and Andrews argue against this concept by holding that "every bit of evidence we have indicates the existence of mineral resources (at lower grades) that could be mined and, further, that either as their price goes up or as their cost goes down (which is to say, as technology of extraction improves), the volume of mineable material increases significantly—not by a factor of 5 or 10 but by a factor of 100 or 1,000." The arguments on this critical issue could be better focused by additional scientific information on the amounts of mineralized rock available at different grades, because existing data are too limited for definite conclusions. Thus, it is not certain that the geologic availability of lower grade resources to the mineral resource supply system is assured so a potential barrier to the resource system remains.

Whether the mineral resource supply system can overcome these restraints in the long run depends ultimately on the magnitude of those mineral resources that we cannot now assess. They are the resources that we are unable to conceive or for which we are unable to foresee the discovery or recovery techniques. There is no question that the resources we know about are a fixed stock and eventually will run out. But, can they be replaced?

Another way of posing this problem is to ask the question whether or not an equilibrium of mineral use can be established that will last indefinitely or nearly so. If the real world of supply and demand is likened to a model where mineral resources are fixed and demand is dynamic and expanding, minerals will run out. But this model is not like the real world where supply and demand are dynamically inter-related and mineral shortages set off a whole set of changes including higher prices, reduced demand, increased conservation, increased substitution, increased recycling, increased technologic and scientific research, increased exploration and increased exploitation of lower grades ores. In the real world, mineral use has evolved to overcome such shortages as firewood from depleted forests, or copper from mined out high grade veins, and such evolution will continue to operate as new shortages arise. This is not to say that such minerals as petroleum in conventional fields, and presently economic deposits of mercury, helium, platinum, and other such geologic rarities will not be exhausted eventually. But our technology likely will evolve to accommodate to a lesser or more expensive supply of such minerals, much as it has developed without abundant supplies of the metals praeseodymium, neodymium, promethium, gadolinium, terbium, and the other rare earths, which were they abundant, probably would be used widely.

Mineral economist John E. Tilton in his excellent book, *The Future of Nonfuel Minerals*, concluded:

> In the more distant future—the twenty-first century and beyond—depletion could become a more pressing problem. It is important to stress this possibility, for the consequences to industrial societies could be more severe. At the same time, it should be noted that the arsenal available to mankind for dealing with this threat is not empty. As pointed out above, public policies that support research in

minerals and reduce their consumption increase the likelihood that technological progress will continue to offset the adverse effects of depletion. Other policies, such as programs to encourage smaller families, to slow the growth of population, may be desirable for other reasons as well. Finally, even in the absence of such policies, one cannot be certain that depletion will ultimately overwhelm the cost-reducing impact of new technology. For as depletion starts to push mineral prices up, it unleashes forces that stimulate the substitution of cheaper and more abundant materials for the increasingly scarce minerals, encourages the search for new and unconventional sources of supplies, and promotes the development of more cost-reducing technologies. Conceivably, these forces could by themselves keep the spector of depletion at bay indefinitely.

It seems clear that our long-term mineral supply system is much stronger than believed by the analysts who regard mineral resources as a fixed and essentially known and fully conceived stock. At the same time, we have the responsibility of keeping the system healthy, and some steps should be taken to do so. The workings of the mineral resource system in its full complexity needs examination to better understand the factors that affect it. A statistical monitoring series that would give early warning of a weakening in the resource replenishment process in any part of the system should be devised and set up. Finally, adequate research and development should be carried out in order to strengthen weak parts of the mineral supply system.

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BASEMENT WELLS IN THE COASTAL PLAIN OF VIRGINIA

David A. Hubbard, Jr., Eugene K. Rader, and Carl R. Berquist

The following catalog of wells drilled to basement in the Coastal Plain of Virginia includes only those for which samples are on file at the Division of Mineral Resources. Basement is defined as Precambrian(?) to Paleozoic igneous and metamorphic rock and Triassic sedimentary rock underlying unconsolidated to semiconsolidated Cretaceous through Quaternary sediment. The majority of the borings were made to obtain water; however, a few exploratory holes are included. In general the exploratory drillings are the deeper ones. The listing (Table 3) is arranged by Division respository number (W-56), county number (211), county, 7.5-minute quadrangle, longitude and latitude, total depth, depth to basement, and basement rock type. Foot notes refer to published references.

Table 3.—Basement wells in the Coastal Plain of Virginia.

Well Repository No./ County No.	County/ Quadrangle	Latitude	Longitude	Total Depth/ Basement Depth (feet)	Basement Rock Type
W-56/211	Richmond (City)/Drewrys Bluff	37°27′26″	77°25′28″	425/71	Granite
W-70/4	Dinwiddie/Petersburg	37°08′27″	77°24′13″	173/170	Granite
W-158, W-159/32, 2	Hampton (City)/Hampton	37°00′15″	77°18′23″	2255/2246	Granite
W-180/4	Mathews/Mathews	37°25′52″	77°19′42″	2325/2307	Granite[2,3]
W-457/32	King William/Manquin	37°41′45″	77°12′38″	3278/1009/2609	Red mudstone[6], granite gneiss[3]
W-515/132	King William/West Point	37°32′43″	76°48′22″	1689/1320	Red sandstone, arkose[5], siltstone
W-539/323	Henrico/Yellow Tavern	37°38′34″	77°29′21″	239/26	Granite gneiss
W-584/208	Chesterfield/Chester	37°20′58″	77°23′08″	300/260	Granite
W-587/74	Caroline/Woodford	38°01′34″	77°29′30″	297/70	Granite gneiss
W-616/325	Henrico/Drewrys Bluff	37°28′15″	77°22′38″	712/249	Sandstone[6]
W-763/36	Greensville/Emporia	36°40′35″	77°32′44″	265/60	Marble
W-781/53	Stafford/Fredericksburg	38°19′31″	77°28′27″	226/185	Granite gneiss
W-935/142	Chesterfield/Chester	37°23′14″	77°34′48″	199/150	Granite
W-953/46	Stafford/Fredericksburg	38°21′52″	77°27′19″	350/180	Granite
W-960/47	Stafford/Fredericksburg	38°22′01″	77°27′11″	325/125	Granite
W-961-48	Stafford/Fredericksburg	38°21′58″	77°26′51″	475/275	Granite
W-969/64	Hanover/Seven Pines	37°36′45″	77°21′03″	608/276	Granite[1]
W-997/37	Greensville/Skippers	36°32′50″	77°31′43″	220/44	Granite
W-1116/22	Caroline/Guinea	38°07′37″	77°29′00″	318/145	Granite
W-1123/172	Henrico/Richmond	37°32′40″	77°22′58″	262/257	Granite[1]
W-1187/24	Dinwiddie/Petersburg	37°11′14″	77°28′33″	126/100	Granite
W-1194/23	Dinwiddie/Petersburg	37°09′35″	77°25′47″	175/95	Granite[5]
W-1198/145	Chesterfield/Chesterfield	37°28′10″	77°33′46″	600/50	Granite
W-1210/276	Prince William/Occoquan	38°39′49″	77°15′05″	577/90	Granite gneiss
W-1230/55	Stafford/Stafford	38°25′30″	77°24′26″	295/210	Granite
W-1297/148	Chesterfield/Drewrys Bluff	37°23′17″	77°25′40″	234/158	Granite
W-1300/80	Hanover/Yellow Tavern	37°39′27″	77°23′17″	334/290	Granite
W-1305/178	Henrico/Yellow Tavern	37°37′54″	77°25′28″	508/200	Granite[1]
W-1388/82	Hanover/Yellow Tavern	37°39′26″	77°23′41″	525/324	Granite
W-1472/83	Hanover/Richmond	37°36′20″	77°22′38″	395/260	Granite[1]
W-1477/184	Henrico/Richmond	37°33′07″	77°23′21″	227/190	Granite[1]
W-1507/25	Dinwiddie/Petersburg	37°08′41″	77°31′18″	108/30	Granite
W-1508/163	Chesterfield/Drewrys Bluff	37°23′49″	77°24′51″	393/130	Granite gneiss[5]
W-1510/160	Prince George/Petersburg	37°11′50″	77°22′42″	224/160	Granite
W-1533/86	Hanover/Ashland	37°45′14″	77°28′05″	295/90	Granite
W-1534/87	Hanover/Ashland	37°45′14″	77°28′05″	350/104	Granite
W-1541/155	Chesterfield/Drewrys Bluff	37°24′41″	77°25′58″	402/70	Granite
W-1553/88	Hanover/Ashland	37°45′14″	77°28′05″	230/104	Granite
W-1634/199	Isle of Wight/Franklin	36°41′49″	76°54′21″	925/913	Granite[2]
W-1687/92	Hanover/Ashland	37°45′14″	77°28′05″	132/98	Granite
W-1753/28	Dinwiddie/Petersburg	37°11′04″	77°24′13″	400/175	Granite
W-1791/99	Hanover/Yellow Tavern	37°38′30″	77°23′26″	632/320	Granite gneiss[1]
W-1800/101	Hanover/Yellow Tavern	37°38′51″	77°24′13″	708/250	Granite[1]
W-1878/104	Hanover/Yellow Tavern	37°40′38″	77°25′51″	640/170	Granite[1,5]
W-1906/172	Richmond (City)/Drewrys Bluff	37°28′32″	77°27′28″	78/20	Granite
W-1907/30	Dinwiddie/Petersburg	37°11′50″	77°27′46″	118/50	Granite
W-1908/171	Chesterfield/Chester	37°18′41″	77°24′06″	140/120	Granite[5]
W-1921/164	Prince George/Carson	37°02′30″	77°23′14″	440/90	Arkose[2,5,6]
W-1936/31	Petersburg (City)/Petersburg	37°12′17″	77°24′04″	143/140	Granite
W-2068/106	Hanover/Yellow Tavern	37°42′24″	77°28′01″	322/83	Granite[1]
W-2071/196	Henrico/Richmond	37°31′00″	77°14′03″	652/640	Sandstone[5,6]
W-2221/110	Hanover/Yellow Tavern	37°41′35″	77°25′48″	300/185	Granite
W-2227/80	Caroline/Ladysmith	38°01′10″	77°30′05″	154/60	Granite
W-2229/469	Spotsylvania/Spotsylvania	38°07′53″	77°30′16″	355/50	Granite
W-2237/93	Hanover/Richmond	37°37′06″	77°23′50″	260/188	Granite[1]
W-2248/113	Hanover/Ashland	37°45′13″	77°28′09″	218/100	Granite[1]
W-2253	Sussex/Manry	36°58′46″	77°00′24″	886/770	Phyllite, schist[2,5]
W-2417/117	Hanover/Richmond	37°36′36″	77°23′32″	600/220	Granite[1]
W-2478/118	Hanover/Yellow Tavern	37°44′15″	77°26′42″	282/105	Granite[1]
W-2500/124	Hanover/Yellow Tavern	37°40′29″	77°25′42″	653/165	Granite
W-2655/128	Hanover/Yellow Tavern	37°40′10″	77°25′51″	310/80	Granite
W-2656/129	Hanover/Yellow Tavern	37°40′05″	77°25′36″	136/132	Granite

W-2683/199	Henrico/Seven Pines	37°31′38″	77°18′23″	540/510	Sandstone[1,6]
W-2751/34	Dinwiddie/Dinwiddie	37°06′21″	77°32′17″	330/78	Granite
W-2756/136	Hanover/Yellow Tavern	37°42′04″	77°26′33″	250/69	Granite
W-2757/135	Hanover/Yellow Tavern	37°42′04″	77°26′33″	250/103	Granite
W-2841/139	Hanover/Yellow Tavern	37°39′21″	77°22′35″	451/306	Granite[1]
W-2926/137	Hanover/Yellow Tavern	37°42′04″	77°26′33″	250/60	Granite[1]
W-2927/36	Dinwiddie/Dinwiddie	37°04′30″	77°35′06″	335/112	Granite
W-2932/200	Henrico/Richmond	37°35′00″	77°29′18″	400/30	Granite[1]
W-3088/196	Chesterfield/Chester	37°20′54″	77°23′08″	372/220	Granite
W-3180	Accomack/Hallwood	37°53′03″	75°31′00″	6272/6018/6134	Red shale[4,6], prophyroblastic argillite
W-3320/226	Sussex/Littleton	36°58′24″	77°09′02″	554/500	Granite[2,5]
W-3250/197	Chesterfield/Chester	37°18′43″	77°24′02″	237/140	Granite
W-3277/142	Hanover/Yellow Tavern	37°42′03″	77°27′17″	250/86	Granite[1]
W-3316/183	Nansemond/Corapeake	36°34′05″	76°35′09″	2017/1920	Sandstone[2,5,6]
W-3317	Charles City/Charles City	37°20′12″	77°06′22″	650/570	Metavolcanics[2]
W-3366/144	Hanover/Yellow Tavern	37°43′48″	77°24′44″	405/165	Granite[1]
W-3367/145	Hanover/Yellow Tavern	37°41′44″	77°26′19″	300/170	Granite
W-3411/198	Chesterfield/Hopewell	37°20′06″	77°16′53″	294/285	Phyllite
W-3443/206	Henrico/Dutch Gap	37°29′32″	77°21′01″	340/220	Sandstone[2,6]
W-3542/147	Hanover/Yellow Tavern	37°41′43″	77°26′05″	290/175	Granite
W-3570/39	Greensville/Emporia	36°41′20″	77°30′56″	225/50	Granite gneiss
W-3574/207	Henrico/Seven Pines	37°31′12″	77°16′36″	610/460	Sandstone[1,6]
W-3579/149	Hanover/Yellow Tavern	37°41′37″	77°26′28″	330/200	Granite
W-3649/153	Hanover/Yellow Tavern	37°41′33″	77°26′40″	200/27	Granite
W-3680/152	Hanover/Yellow Tavern	37°41′37″	77°26′21″	350/50	Granite
W-3791/157	Hanover/Yellow Tavern	37°38′11″	77°22′54″	431/300	Granite gneiss
W-3821/102	Caroline/Bowling Green	38°00′32″	77°22′06″	592/300	Granite gneiss
W-3824/162	Hanover/Yellow Tavern	37°40′21″	77°25′31″	310/68	Granite
W-3876/113	Charles City/Charles City	37°19′55″	77°05′55″	591/585	Amphibolite
W-3900	Hanover/Studley	37°42′48″	77°17′58″	504/500	Granite[1]
W-3901	Hanover/Studley	37°40′55″	77°17′45″	627/527	Granite[1]
W-3902	Hanover/Richmond	37°36′43″	77°24′23″	159/155	Granite[1]
W-3903	Henrico/Seven Pines	37°31′04″	77°20′39″	404/280	Mudstone[1,6]
W-3904	Hanover/Seven Pines	37°37′00″	77°15′55″	600/512	Mudstone[1,6]
W-4069/40	Greensville/Jarratt	36°49′02″	77°28′29″	340/111	Phyllite
W-4159/174	Hanover/Ruther Glen	37°52′53″	77°27′48″	297/37	Mudstone[6]
W-4162/218	Chesterfield/Beach	37°17′07″	77°34′46″	505/70	Granite
W-4208/170	Hanover/Ashland	37°50′56″	77°26′39″	420/229	Mudstone[6]
W-4387/110	Caroline/Ladysmith	38°01′53″	77°31′07″	375/40	Granite
W-4391/179	Hanover/Yellow Tavern	37°37′31″	77°22′48″	320/316	Granite
W-4394/178	Hanover/Yellow Tavern	37°39′59″	77°24′42″	367/260	Granite
W-4397/212	Richmond (City)/Drewrys Bluff	37°27′28″	77°25′16″	292/290	Granite gneiss
W-4505/112	Caroline/Ruther Glen	37°58′22″	77°29′11″	445/40	Granite
W-4540/214	Chesterfield/Chester	37°15′56″	77°24′38″	240/40	Granite
W-4541/42	Greensville/Emporia	36°42′31″	77°31′16″	206/60	Metasiltstone
W-4762/215	Chesterfield/Drewrys Bluff	37°25′15″	77°25′02″	205/176	Granite
/5	Caroline/Bowling Green	38°03′05″	77°20′45″	1550/533	Sandstone[6]

FOOTNOTES

[1]Daniels, P.A., Jr., and Onuschak, Emil, Jr., 1974, Geology of the Studley, Yellow Tavern, Richmond, and Seven Pines quadrangles, Virginia: Virginia Division of Mineral Resources Rept. Inv. 38, 75 p.

[2]Johnson, S. S., 1975, Bouguer gravity in southeastern Virginia: Virginia Division of Mineral Resources Rept. Inv. 39, 42 p.

[3]Le Van, D. C., 1962, Wells drilled for oil and gas in Virginia prior to 1962: Virginia Division of Mineral Resources, Mineral Resources Report 4, 47 p.

[4]Onuschak, Emil, Jr., 1972, Deep test in Accomack County, Virginia: Virginia Minerals, vol. 18, no. 1, p. 1-4.

[5]Teifke, R. H., 1973, Stratigraphic units of the Lower Cretaceous through Miocene series, *in* Geologic studies, Coastal Plain of Virginia: Virginia Division of Mineral Resources Bulletin 83, pt. 1, p. 1-78.

[6]Triassic rocks.

NEW PUBLICATIONS

(Available from the Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; State sales tax is applicable only to Virginia addressees.)

Publication 4. GEOLOGY OF THE GREENFIELD AND SHERANDO QUADRANGLES, VIRGINIA, by Mervin J. Bartholomew; 43 p., 2 maps in color, 37 figs., 5 tables, 1977. Price: $6.00 plus $0.24 State sales tax, total $6.24.

The Greenfield and Sherando 7.5-minute quadrangles, encompassing an area of about 118 square miles (306 sq km), are located in the Blue Ridge, Piedmont, and Valley and Ridge physiographic provinces in Albemarle, Augusta, and Nelson counties, Virginia. A 1- to 3-mile- (2- to 5-km-) wide zone of cataclastic rocks bisects approximately the area from the north-central part of the Greenfield quadrangle southwestward to the southeastern part of the Sherando quadrangle. East of this zone, layered gneiss with northwestward-trending segregation layering was metamorphosed to granulite facies and partially melted during emplacement of massive Lovingston granitic gneiss; both rock units were intruded by massive charnockite during Grenville metamorphism. West of the cataclastic zone, layered gneiss with eastward-trending segregation layering was metamorphosed to granulite facies and intruded by Grenville-age massive charnockite of the Pedlar Formation. The late Precambrian(?) Swift Run and Catoctin volcanic sequence overlies the latter rocks. This volcanic sequence is overlain by the Cambrian clastic and carbonate sequence of the Weverton, Harpers, Antietam, Shady, and Waynesboro formations. These Cambrian rocks occur beneath and adjacent to extensive Quaternary sediments to the northwest of the Blue Ridge in the northwest corner of the Sherando quadrangle. Mafic dikes intruded the area prior to Paleozoic metamorphism and during the Triassic Period.

Thrusting along the Rockfish Valley fault and cataclasis in the zone of cataclastic rocks east of the fault occurred concurrent with regional Paleozoic greenschist-facies metamorphism that produced prominent, overturned to recumbent folds and associated axial-plane foliation. These structures were truncated by younger Paleozoic thrust faults that predate late Paleozoic(?), northeastward-trending, high-angle faults and broad, open, northwestward-trending fold axes. The youngest structures are northwestward-trending, high-angle faults mostly covered by Quaternary sediments.

Currently, there is no mining of mineral deposits in the Greenfield and Sherando quadrangles. Iron and manganese, manganese, and copper were mined sporadically within the Sherando quadrangle from the early 1800's to the middle part of the 1900's at the Mount Torry tract, the Lyndhurst mine, and the Allen mines, respectively.

The report includes two geologic maps in color at the scale of 1:24,000 (1 inch equals approximately 0.4 mile or 0.6 km). They show the Precambrian, Cambrian, Triassic, and Quaternary surface geologic units.

Map. GRAVITY MAP OF VIRGINIA—SIMPLE BOUGUER ANOMALY, by Stanley S. Johnson; color edition; scale, 1:500,000 or 1 inch equals approximately 8 miles (13 km); size, 30 x 60 inches (76 x 152 cm); 1977. Price: $3.00 plus $0.12 State sales tax, total $3.12. Additional charge for one or more unfolded copies by mail is $2.00.

The gravity map for all of Virginia is in 15 colors, each of which delineates every 10 milligals of gravity measurements of the earth. The map is based on a machine-contoured one at the interval of 5 feet. The data for the contouring is the same as that used for the 1:250,000-scale maps at the contour interval of 4 milligals in Virginia Division of Mineral Resources Reports of Investigations 27, 29, 32, 39, and 43 and Publication 6, which were published from 1971 through 1977.

Map. AEROMAGNETIC MAP OF VIRGINIA: IN COLOR, by Zietz, Isidore, Calver, James L., Johnson, Stanley S., and Kirby, John R.; published by the U.S. Geological Survey in cooperation with the Virginia Division of Mineral Resources; color edition; scale 1:1,000,000 or 1 inch equals approximately 16 miles (26 km); size 14 x 18 inches (36 x 46 cm). Price: $1.50 plus $0.06 State sales tax, total $1.56. Additional charge for one or more unfolded copies by mail is $2.00.

The aeromagnetic map of all of Virginia is in 12 colors, each of which delineates every 100 gammas of the total intensity magnetic field of the earth. The data for the contouring for most of the State is from unpublished surveys by the Virginia Division of Mineral Resources during 1962 and 1969-1972 and the U. S. Geological Survey during 1960 and 1972.

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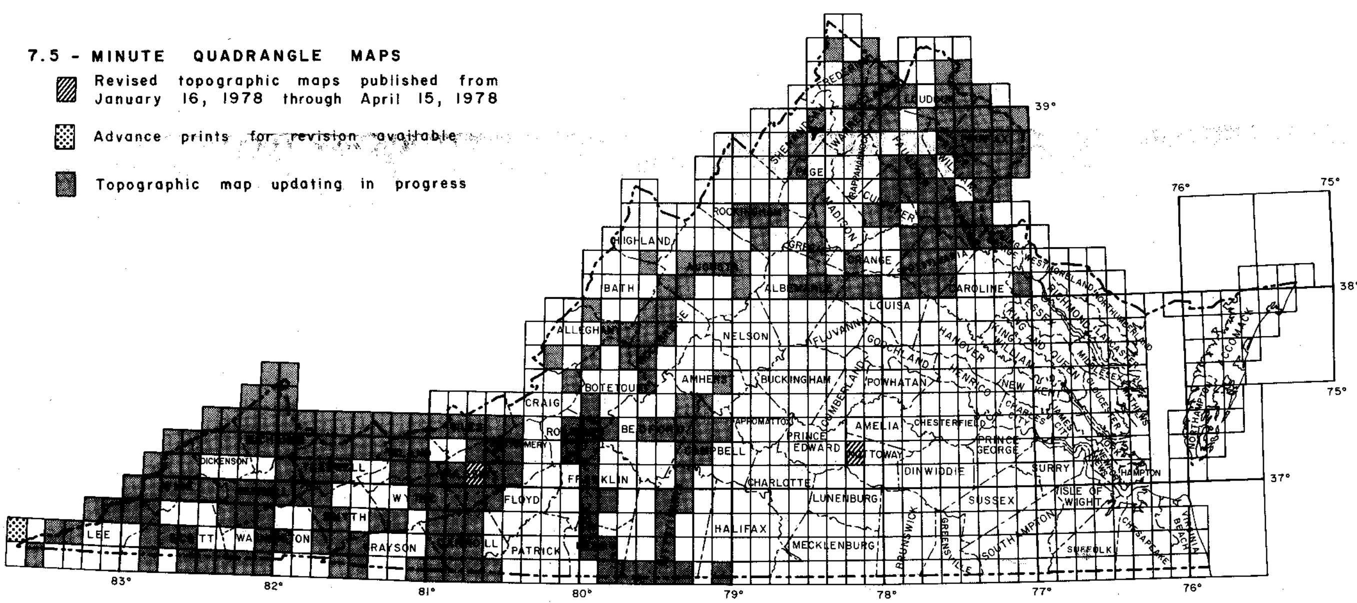

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